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Physics and Finance: S-Terms and Modern Finance as a Topic for Science Studies

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This article argues that modern finance should be an important object of attention. Particularly worthy of study are three demarcations: the changing disciplinary boundary of economics, the distinction between private and public knowledge, and the legal and cultural demarcation between legitimate trading and gambling. The balance between what Barnes calls N-type (natural kind) and S-type (social kind) terms in finance is different from, for example, that in physics, but that is no criticism of finance theory: the activities of those who disbelieve finance theory's efficient market hypothesis probably make the hypothesis more true. The case of Black-Scholes-Merton option pricing theory is drawn on to argue that the loops of self-reference intrinsic to S-terms seem predominantly performative: they increase the truth of finance theory's typical assumptions. S-loops in the financial markets do not always promote stability, however, as is shown here by a case study of the fate of the hedge fund, Long-Term Capital Management.

Some time in the summer of 1994 (the exact date is not known), the Intel Corporation made a disturbing discovery. Its new Pentium Processor contained a flaw in the design of its divide unit. The flaw was a small one: in the worst case, it affected the fourth significant decimal digit in the result of a division, and the pattern of binary digits that triggered it was extremely rare, occurring only once in 9 billion random divides. Nevertheless, the Pentium chip was rapidly becoming the dominant processor in personal computing,

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AUTHOR'S NOTE: This is a preliminary and speculative report in which conjecture is more common than solid finding. I am grateful to the finance theorists and market participants who allowed themselves to be interviewed by me. Helpful comments on earlier drafts were received from Barry Barnes, David Bloor, Michel Callon, Paul Draper, Matthias Klaes, Martin Kusch, Brian Main, Perry Mehrling, Yuval Millo, Myron Scholes, and Steve Stigler, from this journal's referees and from audiences at the Max-Planck-Institut für Wissenschaftsgeschichte (to which this paper was first presented in August 1999), the Cardiff conference Demarcation Socialised, and seminar groups at Edinburgh University, Harvard University, King's College London, and the University of California, Berkeley. Very helpful, too, was a series of electronic mail exchanges with Robert C. Merton as well as Peter L. Bernstein and Mark Kritzman's suggestions

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and Intel had to take the divide bug seriously. Two of its scientists, H. P. Sharangpani and M. L. Barton (1994), took on the task of discovering where divisions matter. Given the pervasiveness of the personal computer, their task amounted to an inquiry into the arithmetical foundations of high modernity. In what areas of modern life, they had in effect to ask, is the use of arithmetic and specifically division intensive enough that a small, rare error could have serious effects? They quickly ruled out applications of personal computers such as electronic mail or word processing, in which the divide bug would never be encountered, and also found that spreadsheet users would be affected by it at a rate much lower than those of physical failures of the processor or of memory chips. In only two areas did divisions really matter. One, of course, was engineering and scientific applications, but even there, in most cases, "meaningful inaccuracies in the end-result will only be seen once in about 1,000 years" (Sharangpani and Barton 1994, 16). The other, according to Sharangpani and Barton, was "financial engineering" (p. 28). Traditional, standard financial calculations "such as present values, annuities, depreciations" (p. 24) would be little affected. But divisions did matter, Sharangpani and Barton found, in the valuation of options and "complex securities." These financial applications were so divide intensive that circumstances could be envisaged in which the flaw might be encountered as often as once a week. In the single most pessimistic sentence in a generally reassuring report, Sharangpani and Barton wrote, "The problem may manifest itself significantly in those programs for valuing the most complicated financial instruments" (p. 27).

The techniques of financial engineering that were vulnerable to the divide bug were all new: the oldest of them, the Black-Scholes option pricing equation, was published only in 1973. But within little more than two decades, these techniques had blossomed to become among the most important calculations performed in the high-modern world.[1] Quite independently of the Intel inquiry, the finance theorist Mark Rubinstein wrote, also in 1994, that the Black-Scholes equation, along with its extensions, was "perhaps . . . the most widely used formula, with embedded probabilities, in human history" (p. 772).

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as to whom to talk to. Barbara Silander kindly word processed the text, and Moyra Forrest and Trevor Pinch provided key documents. The research was supported by the Initiatives Fund of the University of Edinburgh's Faculty Group of Law and Social Sciences and by the UK Engineering and Physical Sciences Research Council's grant (GR/N13999) to DIRC, the Interdisciplinary Research Collaboration on the Dependability of Computer-Based Systems. Given the controversial nature of some of this article's subject matter, the customary disclaimer applies with particular force: the views expressed here are mine, and any mistakes or errors of interpretation are mine alone.

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Yet the mathematicized world of finance theory and financial engineering is almost terra incognita to science studies. There is one significant study of the emergence of modern finance theory by a sociologist of science: Whitley (1986). His article is in part a criticism of the theory: "The oft-repeated claims to be doing 'positive' scientific research in this area reproduce elementary philosophical errors promulgated by many economists" (p. 160). Nevertheless, his study offers a useful historical review and an interesting contrast between the success of finance theory and the relative failure of "operations research" (the other most highly mathematicized specialism within business schools) in providing relevant training and a professional identity for practitioners while sustaining a coherent program of theoretical and empirical work. Aside from Whitley's article and a historical discussion of the concept of "efficient markets" by Walter (1996), the only historical treatments of modern finance theory are by practitioners (especially Bernstein 1992, 1996; Bouleau 1998) rather than by historians of science. Although historians of economics have raised relevant matters—in the light of my title, Mirowski (1989) is particularly pertinent—they too are only just beginning work on finance theory (see Mehrling 1999). There has been sporadic interest by general sociologists (especially Baker 1984 and Abolafia 1996) in financial markets, but sociologists of science are only just awakening to the interest of finance theory. A. Javier Izquierdo Martín, Vincent-Antonin Lépinay, Yuval Millo, and Fabian Muniesa have begun research in the area, but little of their work has so far been published, although see Izquierdo (1998, forthcoming) and Muniesa (2000).[2] Perhaps the most impressive work to emerge (at least in part) from the sociology of science is the detailed ethnographic study of trading and traders used by Knorr Cetina and Brügger to introduce a phenomenological perspective into economic sociology (Knorr Cetina and Brügger forthcoming; Brügger and Knorr Cetina forthcoming; Brügger 2000); this work, however, has so far said little about markets as a place not just of social interaction but also of the application of mathematical theory.[3]

My purpose in this article is to argue for an end to the neglect of finance theory and financial engineering by science studies and to encourage the intensification of the current awakening of interest. If science studies is to fulfil its promise, it must grapple with the myriad ways in which high modernity is a scientific and a technological society: finance theory and its practical applications to the financial markets are among the most important such ways. Financial markets must play a central role in any sensible account of high modernity and of globalization; if high modernity is a "risk society" (Beck 1992), then financial risk—the management of which is a key high-modern industry—is a crucial aspect. Yet the wider sociological profession

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has a tendency not to open scientific and technological "black boxes": for the limited extent to which even the best general sociologists do this when writing about the financial markets, see Boden (2000) and Castells (2000). The central claim of science studies is that modernity cannot be understood properly unless its black boxes are opened; the study of finance theory and of financial engineering offers a potentially crucial test for this claim.

An improved understanding of high modernity via the application of science studies to finance theory and financial engineering is an immodest aspiration. It is, therefore, necessary immediately to emphasize the limited contribution offered by this article. My aim here is threefold. First, I draw attention briefly (and largely in the hope that others will take up these topics) to three demarcations. One is the boundary of economics and the gradual move of financial markets from being a peripheral and even suspect topic to becoming a central one. Another is the distinction between private and public knowledge, the subject of crucial boundary work (see Gieryn 1999). A final demarcation is that between legitimate trading and gambling.

Second, I shall explore Barry Barnes's (1983) contrast between N-type (natural kind) and S-type (social kind) terms. My argument, which parallels, albeit in different terminology, what Michel Callon (1998) has argued for economics more generally, is that finance is a domain of S-type terms. Finance theory is a science and financial engineering is a technology, but there are differences between finance and a natural science such as physics, at least as the latter is ordinarily conceived, and between financial engineering and engineering's more "physical" disciplines. These differences, I argue, are usefully captured by the notion of S-type terms.

The characteristic of S-type terms is the existence of feedback loops between the terms and their referents. My third aim, therefore, is a preliminary examination of some of those loops via a general discussion (which suggests that these loops are typically performative; i.e., they increase the validity of finance theory's assumptions) and via case study of the hedge fund, Long-Term Capital Management (LTCM). Set up in 1993, LTCM enjoyed great success but in August and September 1998 encountered difficulties that brought it close to bankruptcy and prompted its $3.6 billion recapitalization by a consortium of U.S. and European banks, coordinated by the U.S. Federal Reserve Bank. The distress of the previously highly successful fund has attracted a blizzard of comment, much of it blatant schadenfreude focusing on the presence amongst its partners of Robert C. Merton and Myron Scholes, winners of the 1997 Nobel Prize for Economics for their contributions to finance theory.[4] The case of LTCM, I shall argue, is a vivid illustration of the feedback loops characteristic of S-type terms.

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Finance Theory and the Financial Markets

Before I turn to those three main tasks, however, the reader may find some background information helpful. Given the long-established nature and importance of stock markets, particularly in the United States and Great Britain, it is not surprising that much of early finance theory (in the 1950s and 1960s) focused on understanding the behavior of stock prices and the principles of rational selection of portfolios of stock. Key was the development of the "random walk" model of stock prices, which, in the words of Fama (1965),

> says that the future path of the price level of a security is no more predictable than the path of a series of cumulated random numbers. In statistical terms the theory says that successive price changes are independent, identically distributed random variables. Most simply this implies that the series of price changes has no memory, that is, the past cannot be used to predict the future in any meaningful way. (P. 34)

Tightly linked to the random walk model and to its generalization, the martingale,[5] or "fair game" model, was the "efficient market hypothesis," which asserted that mature capital markets, such as those of the United States, were "efficient" in the sense that prices within them "always 'fully reflect' available information" (Fama 1970, 383). (The link between the two ideas is that if the current price of a stock reflects all currently available information, then its future price movements will be shaped only by new information, which by virtue of its being new, is by definition unpredictable.) Alongside these developments was the theory of "portfolio selection," originally developed by Harry Markowitz (1952). Markowitz's student, William Sharpe, along with John Lintner and Jack Treynor, developed what became known as the Capital Asset Pricing Model, in which the key determinant of the expected rate of return on a stock is the stock's β, the covariance of its price with the overall level of the market (see, e.g., Sharpe 1964). The key issue was diversification: the idiosyncratic risk of a particular stock could be diversified away but not the generic risk of overall market fluctuations. Rational investors would therefore require higher expected returns to hold stocks with a high β, a high correlation with the overall market, than low-β stocks.[6]

The emergence of modern finance theory was part of a revolution that had a major impact on an older, largely pretheoretical, and often explicitly relationship-based world of finance. Recalls investment manager and participant historian Peter L. Bernstein (1992),

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> Before the revolution, [the individual clients of] our family-oriented business would come to us and say, "Here is my capital. Take care of me." As long as their losses were limited when the market fell, and as long as their portfolios rose as the market was rising, they had few complaints. They came to us and stayed with us because we understood their problems and the myriad kinds of contingent liabilities that all individuals must face. They recognized that we shared the delicate texture of their views about risk. We joked that we were nothing more than social workers to the rich.

To Bernstein and others, the academic theory of financial markets that had begun to develop in the 1950s and 1960 seemed "alien and unappealing . . . abstract and difficult to understand. . . . It seemed . . . to demean my profession as I was practicing it" (Bernstein 1992, 10, 13). Initially, for example, advocates of the random-walk model were "greeted in some Wall Street quarters with as much enthusiasm as Saddam Hussein addressing a meeting of the B'nai Brith" (Malkiel 1996, 159). Gradually, however, the random-walk model, portfolio selection, and the Capital Asset Pricing Model were adopted by a wide variety of practitioners (see Bernstein 1992, 233-306). The most telling indicator of practitioners' acceptance of finance theory was the emergence in the 1970s of "tracker funds," in which the effort to beat the market by picking promising stocks was abandoned in favor holding all the stocks making up a market index such as the Standard and Poor's (S&P) 500.

Much more rapid in its adoption by practitioners was the theory of option pricing developed by Fischer Black and Myron Scholes (1973) and Robert C. Merton (1973). An option is a contract that gives the right but not the obligation to buy ("call") or sell ("put") an asset such as a block of shares at a given price on, or up to, a given future date. Black, Scholes, and Merton showed that if returns on the underlying asset followed a continuous-time random walk, then the pattern of returns on an option could be replicated exactly by a continuously adjusted portfolio of the asset and government bonds and/or cash. In an efficient market, therefore, the price of an option had to be the cost of the replicating portfolio. If their prices diverged, an arbitrage opportunity existed: in other words, there was risk-free profit to be made by buying the cheaper and selling the dearer of the two. As arbitrageurs did this, their purchases would raise the lower price and their sales would lower the higher price: arbitrage would eliminate any difference between the price of an option and the cost of the replicating portfolio.[7] At the start of the 1970s, options were "specialized and relatively unimportant financial securities" (Merton 1973, 141): the market in them was limited in volume and ad hoc. It amounted to less than one-thousandth of the volume of the New York Stock Exchange, and

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> when an investor wishes to buy a contract he contacts his broker who contacts a member of the Put and Call Dealers Association who acts as a clearing agent, seldom buying or selling options for his own account. These dealers will contact or be contacted by other brokers who sell options for clients. (P. 141)

Because of the time-consuming and complicated nature of these arrangements, "large orders are difficult if not impossible to fill and even small orders may take time to fill" (Black and Scholes 1973, 409, 416).

What gave the work of Black, Scholes, and R. C. Merton its practical significance were two factors. The Chicago Board of Trade, originally an agricultural commodities exchange, spun off the Chicago Board Options Exchange, which opened in April 1973 in what had been the smoking lounge of the Board of Trade, "a limited space that had been converted for the purpose. Soon traders were standing on counters because there was no room on the floor" (Bernstein 1992, 225-26). Such was the success of the new exchange that the Board of Trade soon had to build the Options Exchange its own trading floor, in delightful metaphor suspended above the floor in which trading in futures on physical commodities took place:

> The old trading floor of the Board of Trade occupied an enormous space, about five stories high, with architecture and decoration appropriate to the importance of the commodities traded there. A new floor was suspended between the old floor and the ceiling, and in 1976 that floor of 30,000 square feet became the home of the Chicago Board Options Exchange. (Bernstein 1992, 225-26)[8]

The work of Black, Scholes, and R. C. Merton quickly became an essential resource for traders on the floor of the Options Exchange. All three were involved in supplying market participants with theoretical prices; "soon traders were valuing options on the floor of the [Chicago Board Options] exchange, punching half a dozen numbers into electronic calculators hard-wired with the formula" (Passell 1997, D4). Use of a theoretically based valuation formula rather than simple intuition had intangible as well as practical benefits: "option dealers had newfound respect" (Falloon 1998, 227). The second factor lending significance to Black, Scholes, and R. C. Merton's work was that their underlying methodology, along with the sophisticated mathematics of continuous-time stochastic analysis (see, e.g., Itô 1987) introduced into finance theory by R. C. Merton, could be applied not just to the call options originally traded on the Chicago Board Options Exchange but also to a wide range of financial derivative products (a "derivative" is a product the value of which depends on the price of another asset). To value a derivative and to hedge its risks, suggested Black, Scholes, and R. C. Merton, find the

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replicating portfolio of more basic assets. By the 1990s, the resultant techniques were wide ranging and formidably sophisticated (e.g., see Wilmott 1998 or Hull 2000).

The elaboration of the techniques of Black, Scholes, and R. C. Merton interrelated closely with the development of financial derivatives markets. The Chicago Board Options Exchange was the second modern derivatives market: in the previous year, 1972, the Chicago Mercantile Exchange, like the Board of Trade originally an agricultural commodities exchange, set up the International Monetary Market, trading in currency futures. Soon the Board of Trade itself was trading financial derivatives, and the great success of the Chicago markets attracted international replicants. The London International Financial Futures Exchange (LIFFE), closely modeled on the Chicago markets, began trading in September 1982. As late as 1986, U.S. exchanges still hosted 90% of organized derivatives trading, but since then LIFFE, the Frankfurt-based Deutsche Terminbörse (DTB, now EUREX), the French Marché à Terme des Instruments Financiers (MATIF), the remarkably successful Brazilian BM & F exchange, and a variety of other exchanges saw the "American system" of finance develop momentum overseas.[9] By 1996, greater than 60 percent of world derivative-exchange trading was taking place outside the United States (Steinherr 1998, 170-73). Alongside these organized exchanges, a huge market also developed in "over-the-counter" derivatives, traded directly between institutions. Perhaps the most important of these, because they had no exchange-traded equivalent, were swaps, contracts to exchange two income streams, such as fixed-rate interest and floating-rate interest on the same notional principal sum. By the end of the 1990s, trading volumes on the world's organized derivatives exchanges and over-the-counter market were huge. The total notional amount of derivative contracts outstanding worldwide at the end of June 1999 was $98.7 trillion.[10] Those who have difficulty imagining the magnitude of this figure might note that it is equivalent to some $16,000 for every person on earth. Although "notional amounts" overstate the economic significance of derivative contracts,[11] the derivatives markets are nevertheless of great economic importance.

Demarcations

Three demarcations are key to the development of modern finance theory and financial markets. The first is the boundary of economics as a discipline. For most of the twentieth century, the stock market was a research topic of dubious legitimacy within economics. Famously, John Maynard Keynes ([1936] 1964) scathingly compared stock-market investment to a newspaper

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competition in which contestants win prizes if their judgment of the attractiveness of faces matches the average judgement of all contestants: "we devote our intelligences to anticipating what average opinion expects the average opinion to be" (p. 156).[12] Nor was the great ideological opponent of Keynesianism, Milton Friedman, initially disposed to accept as "economics" Markowitz's development of a theory of the optimum allocation of investments, telling Markowitz at the beginning of his Ph.D. defense, "Harry, I don't see anything wrong with the math here, but I have a problem. This isn't a dissertation in economics, and we can't give you a Ph.D. in economics for a dissertation that's not economics."[13] The eventually Nobel prize–winning paper on option pricing by Fischer Black and Myron Scholes (1973) was initially rejected, without refereeing, by the *Journal of Political Economy* on the grounds that it was "too specialized" (Black 1989, 7). Finance was and is a specialism predominantly within business schools, not economics departments, and "at most universities, the business school and economics faculties barely greeted each other on the street," comments Peter Bernstein (1992, 46). Chicago and MIT were among the few exceptions and became the key sites for the development of modern finance theory. Even as finance has gained legitimacy within economics, with the leading finance theorists winning Nobel Prizes, some traces of division remain. Merton H. Miller (1998), one of those Nobel laureates, wrote that "the huge body of scholarly research in finance over the last forty years falls naturally into two main streams . . . the Business School approach to finance and the Economics Department approach" (p. 1).[14]

With the stock market a marginal topic in economics, it is not surprising that the origins of the random-walk model lie outside the subject. It was first put forward by the French mathematician Louis Bachelier (1900), one of Henri Poincaré's students (Cootner 1964, 17-78), and then independently by the statisticians Holbrook Working (1934) and Maurice Kendall (1953). Later developments came from statistician Harry Roberts (1959) and astrophysicist M.F.M. Osborne (1959). The first economist to contribute centrally to the topic was Paul Samuelson, who began work on it in the mid-1950s, although Sidney Alexander (1961) (see Bernstein 1992, 107) also had long-standing interests in the topic. What Roberts (1959) called "the traditional academic suspicion about the stock market as an object of scholarly research" (p. 3) may well have been caused in part by the dubious legitimacy of stock markets themselves. They were implicated in the Great Depression and, after the latter, had for decades been seen as risky investments. "After twenty-three years, stock prices were still one-third below their 1929 peak," but it "was not just the disaster that turned people off; it was also the association of the market with wrong-doing by people in high places" (Bernstein

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1992, 42). From the 1950s onward, however, the legitimacy of the stock market grew, and large quantities of data on stock price movements became available, as did the necessary computer power for their analysis. Although the institutional separation of much of finance theory from economics departments remained, finance gradually moved to become a central topic, indeed arguably one of the "crown jewels" of neoclassical economics.

A second demarcation, this time concerning the markets themselves rather than the theoretical analysis of them, has been important to their recovery of legitimacy: the distinction between public and private knowledge. That insider trading ought, from an economic point of view, to be illegal is far from clear and has been the subject of much debate. It is perfectly reasonable to argue, for example, that with insider trading, "stock prices better reflect information" (Leland 1992, 859) and markets are in that sense more efficient: insider knowledge, after all, is likely to be fresh knowledge and more reliable than market rumor. Nevertheless, the sense that a "fair" market in stocks requires a ban on insider trading gained hold in the United States and has gradually spread to other jurisdictions, with, in consequence, delicate "boundary work" (Gieryn 1999) being necessary to maintain and police the distinction between private and public knowledge (see Boyle 1996, chapter 8).

A third crucial demarcation is between legitimate trading and gambling. In 1936, Keynes could write, "It is usually agreed that casinos should, in the public interest, be inaccessible and expensive. And perhaps the same is true of Stock Exchanges" (Keynes [1936] 1964, 159). That a financial market is not a casino is key to the former's claim to legitimacy, but more is at stake in the maintenance of the boundary than cultural acceptability alone. Legal prohibitions on gambling have been strong in most parts of the United States, and in Britain, although gambling is permitted, gambling debts are not legally enforceable. It is thus critical to the practical feasibility of financial markets that their activities be distinguishable legally from gambling. Significant initial obstacles to the emergence of financial derivatives markets were caused by the way in which the distinction between gambling and trading in futures[15] on physical commodities had traditionally been drawn. The Chicago Board of Trade, for example, had for many years used Illinois law prohibiting gambling in its battles against the incursion of "bucket shops" into the futures market. The key distinction the board sought to have enforced legally was between the contracts it traded, which could be settled by delivery of a commodity such as grain, and those, typical of the bucket shops, that could be settled only in cash. The former were legitimate; the latter, the board argued, were simply wagers on price movements and so constituted gambling and were illegal. The distinction was a contested one: the futures-trading activities

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of the board itself were on occasion ruled to be gambling despite the possibility of settlement by physical delivery, and decisions of lower courts had to be appealed—successfully—to the U.S. Supreme Court (Ferris 1988, chapter 8).[16] To take the possibility of physical delivery rather than mere cash settlement as a defining characteristic of a legitimate futures trade became problematic as the Chicago markets moved from agricultural commodities to financial ones. The issue has gradually been resolved in both the United States and United Kingdom by carefully framed legislation—legal boundary work, one might call it—legitimizing contracts that have to be settled in cash, but initially, it was a significant constraint on and shaper of the development of financial markets. In the late 1960s, leading figures in the Chicago Board of Trade, then still a physical commodities exchange, sought to expand its activities into the financial sphere by developing a market in futures on the Dow Jones Industrial Average. However, because an index is an abstraction, such a contract could be settled only in cash, and the leading securities lawyer they consulted, Milton Cohen, advised them that the idea was "likely to run afoul of . . . Illinois State gambling laws" (Falloon 1998, 210). The idea of an options exchange was settled on as likely to be less problematic legally: a contract for an option on a particular stock could, at least in principle, be settled by delivery of stock certificates, not just in cash.

As the legal demarcation between trading and gambling was redrawn, barriers to cash settlement disappeared, and futures and options contracts on abstract quantities such as indexes became unproblematic: indeed, a general characteristic of the development of the financial markets has been a growth in the degree of abstraction of the assets being traded. In wider cultural terms, however, the issue of the boundary between gambling and trading has not entirely vanished. It has been reopened in recent years above all by the development in the United States of day trading, in which amateur traders seek to make quick profits (usually on the stock market, especially NASDAQ, rather than in derivative markets) by buying and selling assets within short periods of time. Day trading has been made possible by declining transaction costs and the possibility of executing transactions electronically: a key development was NASDAQ's Electronic Small Order Execution System, introduced in 1985. There is anecdotal evidence to suggest that many day traders are "momentum traders" who hope to spot market "trends," buying as prices start to rise and selling as they start to fall. In the words of the General Accounting Office (2000), "As a result of their trading strategies, day traders are not considered to be investors. They do not pay close attention to such factors, as price/earnings ratio or investing and earnings models, which investors are taught to follow" (p. 9). The issue of the status of day trading was dramatically

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highlighted in July 1999, when a mentally disturbed day trader in Atlanta, Georgia, who had run up large losses, killed his family and people at two day-trading firms.

N-type and S-type Terms

The various demarcations and boundary work surrounding finance theory and the financial markets indicate a variety of ways in which science-studies approaches could be applied in this area. Another, arguably deeper, reason why finance theory and financial engineering are of interest can best be elucidated by Barry Barnes's (1983) distinction between N-type terms and S-type terms. An N-type, or "natural kind," term is one in which the application of the term to a particular entity can be thought of as a process in which the empirical properties of the entity are judged against a pattern, and the term is applied or not applied according to the perceived closeness of fit. Consider, for example, the term *leaf*. An individual's socialization, what he or she "has been shown of leaves, and told of them, is presumably crucial to an understanding" of what he or she "takes to be leaves." But the "empirical characteristics of a putative leaf are then sufficient to decide whether or not it matches the pattern" (Barnes 1983, 525). In contrast, with an S-type, or "social kind," the process of concept application is "performative" (Austin 1962). The simplest, most obviously performative case of an S-term is the situation in which a particular individual is "entitled to *pronounce* any entity an S, or any entity of kind A an S, and thereby *make* it an S" (Barnes 1983, 526). A minister of religion, for example, has the right in appropriate circumstances to *make* a man a "husband," and a woman a "wife," simply by pronouncing them to be "husband" and "wife." To say, to hand signal, or to type "sold" or its equivalent in a financial market is to make a sale (see Brügger and Knorr Cetina forthcoming). That something is referred to as an "S" is what makes it an S (Barnes 1983, 525-26).

Of course, there will in many cases not be a single accepted authority nor a clearcut procedure by which S-type references are made to "stick," and then the elementary form of "performative utterance" (Austin 1962, 6) turns into the full complexity of sociology. Consider, for example, even a simple case of whether a social actor is powerful: "John is the leader of the gang. He is the leader because the members know him to be the leader, and act routinely on the basis of what they know" (Barnes 1988, 49). He can be powerful without there being an authority to designate him as such; his power and members' beliefs about his power are mutually constitutive. His power may be doubted,

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questioned, wax, and wane. The key point, however, is that in both the simplest and the most complicated and contested situations, S-terms have self-referential and self-validating (or occasionally self-invalidating) aspects. As Austin (1962) puts it, "To name the ship *is* to say (in the appropriate circumstances) the words 'I name, &c.'. When I say, before the registrar or altar, &c., 'I do,' I am not reporting on a marriage: I am indulging in it" (p. 6). If "I name this ship," or "I do," or "sold" describe anything, they describe themselves, and by uttering them, one makes them true: they are self-referring, self-validating speech acts. Again, naming, marriage, and selling are simple cases. In more complex cases, the loops of self-reference and self-validation are more complicated: "One must typically expect a tangle of diverse and conflicting usages . . . [a] spaghetti junction" (Barnes 1988, 526). But if we are dealing with an S-term, the loops are there, creating, and perhaps undermining, its validity.

The notions of N-terms and S-terms are ideal types, and the distinction does not correspond to the demarcation between the natural sciences and other forms of knowledge. The past three decades of the social studies of science can be summarized as the discovery of the S-aspects of apparent N-terms, but those who doubt that the natural sciences contain S-terms need consider only measurement. The property of being the standard meter, for example, is an S-term: a bar, or collection of other physical phenomena, is the standard meter because the relevant authorities have designated it the standard meter. Arguably, our field's enthusiasm for discovering the S-aspects of terms led to underemphasis on their N-aspects, perhaps because it is often thought, quite wrongly, that if a concept were an N-term it would somehow escape sociological analysis (see Barnes, Bloor, and Henry 1996 and Latour 1999 for—radically different—approaches to the sociological analysis of scientific terms that encompass their N-aspects). This, however, is not a debate that need detain us here, because the issue I wish to raise is most easily conceptualized by setting aside complications and focusing on the key point: that S-terms are constituted by loops of self-reference and self-validation. As Hacking (1992) puts it, some "human kinds" (a notion roughly equivalent to S-terms) "differ from those routinely thought of as natural kinds. The classification of people and their acts can influence people and what they do directly. And I believe this is true only of people. . . . Human kinds have feedback, a looping effect" (p. 190).

For many practical purposes, an individual can often ignore S-terms' loops of self-reference and self-validation and, thus, in effect, treat S-terms as if they were N-terms. If the gang is big enough and the loops stable enough, that a particular individual is the leader can seem a fact of the same type as the

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fact that the individual has brown eyes. In current Euro-American societies, we have for some time been able to be confident that a piece of paper treated as money today will also be treated as money tomorrow. The self-validating inference loop that constitutes money has become so taken for granted as to be invisible. The patterns of belief that constitute money become evident only when those beliefs become precarious in times of social collapse or hyperinflation. Because of the frequent invisibility of S-loops and because of the dominance of what one might call the epistemology of N-terms, influential positions within sociological theory have frequently ignored the loops of self-reference and self-validation; the Durkheimian treatment of "social facts" is an example. One of the few exceptions (at least within mainstream sociology and prior to the 1960s) is a classic paper by Robert K. Merton (1949) on "the self-fulfilling prophecy." Merton's paper begins with "a sociological parable": the failure of a bank. A rumor that a bank is unsound causes depositors to withdraw their money; others observe these withdrawals and seek to withdraw in their turn, and eventually the rumor of the bank's insolvency makes itself true. Merton goes on to diagnose the role of self-fulfilling prophecy in a variety of aspects of social life, in particular "ethnic and racial prejudices." Whites often excluded blacks from trade unions on the grounds that they were strike-breakers and prepared "to take jobs at less than prevailing wages." By excluding them from unions, they "invited a series of consequences which indeed made it difficult if not impossible" for many blacks to avoid being strike-breakers and taking jobs at low wages (Merton 1949, 182).

R. K. Merton's analysis of self-fulfilling prophecies is insightful and, in its diagnosis of the foundations of ethnic prejudice, impassioned and ahead of its time. Nevertheless, as Barnes (1988, 537-38) points out, it does not go quite far enough. Implicit, and sometimes explicit, in Merton's analysis is an emphasis on the pathological aspect of self-fulfilling prophecy: a solvent bank is made insolvent by a false rumor. Self-fulfilling prophecy can indeed be a "vicious circle in society" (Merton 1949, 193), but as Barnes points out, the creation of a sound bank is as much a self-fulfilling prophecy as the creation of an insolvent one. "The presence of deposits makes the 'bank' a safer one, one better able to attract deposits. Further deposits flow in. Growing convictions of security are the basis for yet more convictions of security" (Barnes 1983, 538). What Merton (1949) calls "belief in the validity of the interlocking system of economic promises men live by" (p. 180) is as much a self-fulfilling prophecy as belief in its invalidity. The virtuous circles of social life are as much self-fulfilling prophecies as the vicious ones. Indeed, as Barnes points out (1983, 538; see also Barnes 1988, 1995), "the tendency for reinforcing systems [of S-type inferences] to persist" makes intelligible "the

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development and stabilization of custom" and provides a potential solution to the problem of social order quite different from, say, the classical Parsonian solution that has been undermined by ethnomethodological critique (see Heritage 1984).

Finance, S-terms, and Efficient Markets

That finance is a domain of S-terms is in one sense self-evident: it is a domain of money, and money is quintessentially an S-term. Going beyond that banal observation, however, requires investigation of the potential feedback loops between finance theory and its object of study, and that is a task that has seldom been attempted (the major exception is in the work of Merton 1949, discussed below). Most discussion of finance theory is framed, implicitly, by N-epistemology. Consider, for example, the efficient market hypothesis. Even the most sophisticated contributions to the debate about its validity (such as Shleifer 2000) typically frame the question as one of the degree of fit between markets as empirical entities and the hypothesis as pattern. That markets are historically changing entities and that their characteristics may be influenced by the pervasiveness of belief in the hypothesis are not usually considered. All sorts of interesting lines of empirical enquiry are thereby blocked. For example, how are the feedback loops between the hypothesis and the markets to be characterized? Day traders' momentum trading, for instance, is predicated implicitly on disbelief in the random walk and martingale hypotheses (I know of no study of what proportion of traders have actually heard of the hypotheses), because the belief that one can spot trends implies that how a stock has reached its current price helps predict the future movements of that price. If enough day traders believe in trend spotting and momentum trading and if they form a large enough part of the market (by 1999, day trading was estimated to form 10 to 15 percent of the overall volume of trading on NASDAQ),[17] then their trading activities may actually create trends: the purchases of those who think they have spotted a rising trend may cause prices to continue to rise. If that were the case,[18] it would constitute positive feedback (disbelief in the efficient market hypothesis creating phenomena at variance with it). Nevertheless, it seems plausible that the predominant pattern is negative feedback—that the search for pricing anomalies from which to profit causes those anomalies to disappear, in other words, that the activities of those who believe the market not to be efficient help make it efficient.[19] It is interesting to speculate about the opposite situation—would markets that almost all participants believed to be efficient (and in

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which, for example, they simply invested in index funds) actually become inefficient?[20]—but belief in the efficient market hypothesis is not yet sufficiently widespread to make this other than a speculation.

The Performativity of Finance Theory

One of the few commentators on the financial markets to emphasize their "S-ness," which he calls "reflexivity," is the financier George Soros (1998). "In the social sciences," writes Soros, "thinking forms part of the subject matter whereas the natural sciences deal with phenomena that occur independently of what anybody thinks" (p. x). Soros suggests an incompatibility between an emphasis on reflexivity and "prevailing theories about efficient markets and rational expectations" (p. 41). That, however, need not be the case. As we have seen, the feedback loops between belief or disbelief in the efficient market hypothesis, and actions in the financial markets probably tend to eliminate phenomena at variance with the hypothesis. More generally, it seems perfectly plausible that S-ness of finance theory is predominantly performative.

Consider, for example, Black-Scholes-Merton option pricing theory.[21] The centerpiece of this is the famous Black-Scholes equation for pricing an option. Let V be the value of an option, S the price of the underlying asset, σ the volatility (standard deviation) of the asset price, r the risk-free rate of interest, and t time. Black, Scholes, and Merton showed that

$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS\frac{\partial V}{\partial S} - rV = 0.$$

The boundary conditions and, hence, solution are given by the nature of the option. This "looks" like physics. The Black-Scholes equation is a form of the heat equation

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial x^2},$$

where u is temperature, t is time, and x is a spatial variable (distance along a bar, say): the transformation needed to make the Black-Scholes equation take this form is given in Black and Scholes (1973, 643). The underlying model of asset price movements is

$$dS = \mu S dt + \sigma S dZ,$$

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where μ is the "drift" of the asset price and Z is a variable whose increments over successive time periods are independent and whose increment between times t_{i-1} and t_i follows a normal distribution with mean zero and variance $t_i - t_{i-1}$. Again, that is familiar to physicists: it is the standard stochastic model of Brownian motion, of the movements of a tiny particle subject to minute, random collisions. Indeed, the mathematical similarity of physics and finance has led to a significant migration in recent years of physicists into the latter field.

Finance, however, is not physics: the balance of N-type and S-type terms in the two fields is different. The dominance of N-type epistemology makes this remark sound like a criticism of finance theory, but it is not. Consider the assumptions underpinning the standard derivation of the Black-Scholes option pricing equation, which are typical of much of modern mathematical finance theory. These include not just the Brownian-motion assumption about asset price movements but also, for example, (1) the assumption that the composition of the replicating portfolio can be revised continuously without incurring transaction costs in doing so (in other words, that in any given time interval, however small, an asset sale or purchase can be made at the prevailing market price); (2) the assumption of the possibility of borrowing or lending indefinitely large amounts of money at the risk-free rate of interest; and (3) the presence of arbitrageurs able to exploit, and thus eliminate, any discrepancy between the prices of an option and of its replicating portfolio.

At the start of the 1970s, when Black, Scholes, and Merton were producing their analyses of option pricing, the empirical validity of these assumptions was at best dubious. Stock market transactions, for example, were expensive; they could be relatively slow to implement. Most market participants could borrow only limited amounts and at significantly higher rates of interest than they could earn by lending; the extent to which arbitrageurs were present is uncertain, and high transaction costs and the sporadic, ad hoc nature of the option market meant arbitrageurs would have encountered significant difficulties implementing arbitrage strategies. When Black and Scholes (1972) analyzed the options market as it then existed, they found that the writers of options "obtain favorable prices" and their purchasers unfavorable ones, as judged by the model, while "there tends to be a systematic mispricing of options [as against the model] as a function of the variance of returns on the stock." Options on "high variance securities tend to be underpriced, and . . . contracts on low variance securities tend to be overpriced" (pp. 413-15). These discrepancies persisted, Black and Scholes pointed out, even though in principle they offered opportunities for profitable arbitrage. High transaction costs meant that apparent arbitrage opportunities did not really exist, and trading at prices other than those suggested by the model was therefore stable (pp. 409, 416).

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The opening in April 1973 of the Chicago Board Options Exchange began to change this situation. Initially, prices on the exchange still differed sharply from Black-Scholes-Merton values. The key difference, however, was that arbitrage opportunities were identified—the model served as "a benchmark for arbitrage" (Steinherr 1998, 28)—and in a continuous, liquid market, in which participants had access to substantial amounts of capital arbitrage opportunities were actually exploited.[22] Although the detailed history of the use of the Black-Scholes-Merton model on the Chicago Board Options Exchange remains to be investigated, it appears that the key arbitrage was "spreading": if, according to the model, one option was overpriced and another on the same stock was underpriced, arbitrageurs would sell the overpriced and buy the underpriced option. In the early months of the exchange, arbitrage profits were available from spreading (Galai 1977), and pursuit of them would have drawn prices toward their Black-Scholes values. The model was also incorporated into the risk-management procedures of the firms providing traders' capital.[23] Indeed, the model seems soon to have been used directly to set prices. Fischer Black (1975) produced and sold to market participants sheets showing the Black-Scholes values of options for different stock prices, volatilities, times to expiry, and exercise prices. One option theorist, Mark Rubinstein, recalls starting to trade options on the Pacific Stock Exchange in 1976 and being struck by the exact correspondence of the posted price of the options he was trading with Black's sheets.[24] "Traders now use the formula and its variants extensively," wrote Black (1989). "They use it so much that market prices are usually close to formula values even in situations where there should be a large difference: situations, for example, where a cash takeover is likely to end the life of the option or warrant." (p. 8).

Over the past three decades, then, the typical assumptions of finance theory have become empirically more realistic. Some of the processes involved have nothing directly to do with finance theory. The development of information and communication technologies has increased the speed with which trades can be executed and greatly reduced their cost. The free-market political climate of the 1980s' United States and United Kingdom played its part, particularly the "Big Bang" deregulation of the City of London by Mrs. Thatcher's government, which opened up the city's cartels to competition and thus greatly lowered transaction costs. The origins of other processes increasing the veridicality of finance theory's assumptions are simply unclear. The key innovations of "repo" and "reverse repo" were found in the U.S. bond market in the 1980s but are now found in the U.K. market as well. A repo, or repurchase agreement, involves organization A borrowing money from organization B to buy bonds that are held by B as collateral for the loan. When A sells the bonds, it repurchases them from B. Reverse repo involves A

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borrowing bonds from B, selling them, delivering the proceeds to B, and eventually A repurchasing the bonds and returning them. The institutions of repo and reverse repo make it possible to borrow or to lend huge amounts at very close to the risk-free rate of interest, so making a key assumption of finance theory far more realistic, but they have yet to attract their historian, so their origins remain unclear.[25]

Crucially, however, finance theory itself has played an important role in its assumptions becoming more realistic. The growth of arbitrage, for example, was greatly encouraged by the huge success of the bond arbitrage desk headed by John Meriwether at the investment bank Salomon Brothers. Developing close links with academic finance theory (and hiring, for instance, Robert C. Merton's student Eric Rosenfeld), Meriwether and his team contributed enormously to Salomon's profits by identifying and exploiting arbitrage opportunities.[26] Their success was quickly noted by others, and both the number of arbitrageurs and the capital available to them grew rapidly. Because arbitrage is the key finance-theory mechanism by which price discrepancies are eliminated, this is a clear instance of the theory's performative aspect. More generally, Black-Scholes-Merton option pricing theory and its many developments facilitate the introduction of new derivative products by showing how they can be priced and how their risks can be hedged. The new products increase the completeness of the markets (in the sense that insurance against a greater range of risks can be purchased), and the construction and adjustment of replicating portfolios to hedge the risks of the new derivative products increase the liquidity of the markets in the underlying assets.

As noted above, nearly all those writing about finance theory discuss it in N-terms and fail to notice these performative, S-aspects. That the main exception, Robert C. Merton, should be the son of Robert K. Merton, theorist of the self-fulfilling prophecy, is surely not coincidental. As noted above, Robert C. Merton's key technical innovation was the introduction to finance theory of the rigorous mathematics of stochastic processes in continuous time: Itô calculus permitted Merton to replace Black and Scholes's original derivation of the option pricing equation, based on the Capital Asset Pricing Model, with a different derivation, not dependent on this model but based on the demonstration that the hedge offered by the replicating portfolio is exact, if the latter is adjusted continuously. Merton is sharply aware that the mathematics of continuous time is only an approximation to the reality of the markets: even in 2000, there is still a finite time interval between the decision to revise a portfolio and the implementation of the revision. But this and other assumptions of finance theory are becoming more realistic, argues Merton: the "financial-innovation spiral" of new products, new markets, greater completeness, increased volume, and lower transaction costs pushes toward "the

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theoretically limiting case of zero marginal transaction costs and dynamically complete markets" (Mason et al. 1995, 19). As the spiral evolves, argues Merton (1992), "reality will eventually imitate theory" (p. 470).

Long-Term Capital Management[27]

I have argued (although I would not claim to have demonstrated) that finance theory has S-loops and that those loops are predominantly performative: they typically act to increase the veridicality of finance theory's assumptions. It would, however, be mistaken to claim that the S-loops of the financial markets always promote stability. That is the interest here of the fate of LTCM. As noted at the start of this article, commentary on LTCM has tended to focus on the personalities involved and on the assignation of blame to particular individuals (Lowenstein 2000 is the most recent contribution in this vein), but this individualized focus diverts attention from what is genuinely interesting about the episode.

LTCM was an investment partnership set up in 1993 by John Meriwether, previously head of Salomon Brothers' bond arbitrage desk and a senior manager in the bank. Meriwether recruited to LTCM from Salomon and elsewhere an impressive team of experienced traders and specialists in mathematical finance. Much of LTCM's trading was with leading banks, and it largely avoided risky "emerging markets," preferring well-established ones such as those in government bonds of the leading industrial nations, in swaps, in options, in mortgage derivatives, and in certain very restricted categories of stock.[28] Following the tradition established by Meriwether at Salomon, the fund eschewed speculation based on intuitive hunches. It built carefully researched mathematical tools for searching for profit opportunities and invested in a way designed to be insulated from market movements, seeking pricing anomalies around which to base arbitrage strategies. Although it had to borrow large amounts (e.g., using repos) and take large market positions to make an adequate return from what were often small anomalies, LTCM scrupulously measured and controlled the risks it was taking. From the start of trading in 1994 to the spring of 1998, it was strikingly successful. But following Russia's devaluation of the ruble and partial default on its ruble-denominated debt in August 1998, market conditions became unusually difficult. The withdrawal in 1998 of Salomon Smith Barney from global arbitrage, following its takeover by the Travelers Corp. and the pending merger of the latter with Citicorp (Booth 1998), may also have been an important background factor. By late September 1998, LTCM was close to bankruptcy. As LTCM's difficulties grew, the U.S. Federal Reserve Bank feared the conse-

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quences for already nervous capital markets of a sudden forced liquidation of the fund's large positions and therefore coordinated LTCM's recapitalization by a consortium of U.S. and European banks. The consortium has now recovered and indeed made a profit on this investment, and the fund has now been wound up. No public money was spent on the recapitalization, and—a small number of rich individual investors aside—the losses were to a few wealthy institutions and to LTCM's partners and employees.[29]

The fund's market positions were varied, but a common theme underlay many of them. Using extensive statistical databases and theoretical reasoning, the firm would identify pairs of financial assets the prices of which ought to be closely related, which should over the long run converge, but which for contingent reasons had diverged: perhaps one was temporarily somewhat easier to trade than the other and therefore more popular, or perhaps institutions had a particular need for one rather than the other. The fund would then buy the underpriced, less popular asset and borrow and sell the overpriced, more popular asset. The close relation between the two assets would mean that general market changes such as a rise or fall in interest rates or in the stock market would affect the prices of each nearly equally, and long-run convergence between their prices would create a small but low-risk profit for LTCM. The partnership knew perfectly well that over the short and medium term, prices might diverge further, but the risks and the consequences of their doing so were carefully calculated by using statistical "value-at-risk" models, which measure the potential losses from adverse market movements and which are now used by all the sophisticated players in the financial markets. As Perold (1999, A10) and Dunbar (2000, 187) note, LTCM also "stress-tested" its trading positions to gauge the effect on them of extreme events not captured by standard statistical models, such as the failure of European monetary union or stock exchanges crashing by a third in a day.

The Russian default was just such an extreme event, although one that no one had anticipated: the surprise was not that Russia was in economic trouble but that it defaulted on debts denominated in rubles rather than simply printing more money and also that it temporarily blocked some foreign exchange transactions by Russian banks. LTCM itself had only a minor exposure to events in Russia, but the precise form of Russia's actions caused significant losses to Western banks. A hedge fund called High Risk Opportunities failed, and (quite unfounded) rumors began that Lehman Brothers, an established investment bank, was also about to do so. Suddenly, market unease turned into self-feeding fear. A "flight to quality" took place, as a host of institutions sought to liquidate investments that were seen as difficult to sell and potentially higher risk, replacing them with lower risk, more liquid alternatives. Because LTCM's "convergence arbitrage" generally involved holding the

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former and short selling[30] the latter, the result was a substantial market movement against the fund.

Although the evidence is still largely only anecdotal, three additional factors seem to have worsened the effect of the flight to quality. First was the simple human fact that it took place in August, when many traders and managers are on holiday and markets tend to be thinner and less liquid than usual anyway. The second factor was that LTCM was by no means the only market participant involved in convergence arbitrage. Its very success had encouraged imitation: other hedge funds and many of the world's leading banks, notably Wall Street investment banks, also had broadly similar large positions. However, Salomon had been engaged for some time in unwinding these positions and continued to do so; as other convergence arbitrageurs suffered losses in August 1998, they too had to unwind positions similar to LTCM's, thus worsening the move of prices against the latter. The third factor was that, as Dunbar (2000) points out, the investment banks employed value-at-risk models not just as LTCM did (to gauge the overall risks faced by the fund) but as a management tool. By allocating value-at-risk limits to individual traders and trading desks, big institutions prevent the accumulation of overrisky positions while giving traders flexibility within those limits. However, if adverse market movements take positions up to or beyond those limits, value at risk becomes a stop-loss rule: the traders involved have no alternative but to try to cut their losses and sell, even if it is an extremely unfavorable time to do so. A direct S-loop thus seems to have existed between value-at-risk models and the markets. In August 1998, widespread efforts to liquidate broadly similar positions in roughly the same set of markets seem to have intensified the adverse market movements that were the initial problem. Crucially, they also led to greatly enhanced correlations between what historically had been only loosely related markets, across which risk had seemed to be reduced by diversification.

When used as management tools, value-at-risk models (intended to describe the market as if it were an external thing) thus became part of a process that magnified adverse market movements, which reached levels far beyond those anticipated by these models. For example, if the account of LTCM's risk modeling in Dunbar (2000) is correct, the fund's August 1998 loss had a probability so low that its occurrence even once in the lifetime to date of the universe was very unlikely. Value-at-risk models with stop-loss rules, other forms of stop-loss, and the need to liquidate positions to cover losses and meet margin calls seem to have combined to cause a failure of arbitrage, the key finance-theory mechanism limiting and eliminating price discrepancies. As "spreads" (the difference between prices of related assets) widened and thus arbitrage opportunities grew more attractive, arbitrageurs

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did not move into the market, narrowing spreads and restoring normality. Instead, potential arbitrageurs continued to flee, widening spreads and intensifying the problems of those who remained, such as LTCM.

LTCM, however, was constructed so robustly that these problems, although they caused major losses, were not fatal. In September 1998, though, an S-loop of a simpler, more brutal kind set in, in effect a run on a bank. LTCM's difficulties became public. For example, on September 2, Meriwether sent a private fax to LTCM's investors describing these difficulties and seeking to raise further capital to exploit what (quite reasonably) he described as attractive arbitrage opportunities.[31] The fax was posted almost immediately on the Internet and seems to have been read as evidence of desperation. The nervousness of the markets crystallized as fear of LTCM's failure. Almost no one could be persuaded to buy, at any reasonable price, an asset that LTCM was known or believed to hold, because of the concern that the markets were about to be saturated by a fire sale of the fund's positions. In addition, LTCM's counterparties—the banks and other institutions that had taken the other side of its trades—tried to protect themselves as much as possible against LTCM's failure by a mechanism that seems to have sealed the fund's fate. LTCM had constructed its trades so that solid collateral, typically government bonds, moved backward and forward between it and its counterparties as market prices moved in favor of one or the other. Under normal circumstances, when market prices were unequivocal, it was an eminently sensible way of controlling risk. But in the fear-chilled, illiquid markets of September 1998, prices lost their character as clear facts. As was in effect their contractual right, LTCM's counterparties marked against LTCM; that is, they chose prices that were unfavorable to LTCM, seeking to minimize the consequences for their balance sheets of LTCM's failure by getting hold of as much of the firm's collateral as possible. Fearing LTCM's failure, they made it inevitable by draining the firm of its remaining capital.

Subsequent events offer an intriguing coda. The episode seems not to have been simply a short-lived market aberration. Despite the general return of confidence following the Federal Reserve's three interest rate cuts in the autumn of 1998, spreads remained stubbornly high (e.g., see Scholes 2000 and the Bank of England's November 1999 *Financial Stability Review*).[32] The reasons are complex and have come to include the healthy state of public finances in the United States (and also the United Kingdom), which has reduced government bond issuance, thus raising bond prices, depressing bond yields, and increasing spreads against bonds. Another factor, however, appears to have been the continued absence of arbitrage capital and other sources of liquidity (see Scholes 2000 on the latter factor). LTCM, although the most dramatic victim of 1998, was by no means the only institution

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damaged. The proprietary trading activities of many banks also incurred heavy losses, and the leading American investment banks, which suffered substantial falls in their share prices, seem to have withdrawn from convergence arbitrage almost completely. The flight of arbitrageurs was not merely a temporary phenomenon of August and September 1998 but persisted.[33] Whether convergence arbitrage will return to the levels of the mid-1990s or whether the events of 1998 marked the start of a more permanent regime shift remains to be seen.

Conclusion

As indicated in the author's note at the start of this article, much of what is said here is speculative. Nevertheless, I hope that I have convinced the reader that modern finance offers intriguing material for science studies research. It is among the most thoroughly scientized parts of high modernity and, although I have not emphasized the point here, also among the most technologized. A modern financial market, such as the Chicago markets, is a sociotechnical system: the pit remains a place of the body, in which voices and hand signals still make deals, but surrounding the pit and increasingly encroaching into its domain are information and communication technologies. In other markets, the pit has already vanished, leaving a system that is technological throughout. The finance theory deployed in these sociotechnical systems is among high modernity's most sophisticated mathematical products and, if Intel's analysis of the implications of the divide bug is correct, arithmetically the most intensive among them.

What adds to finance theory's interest to science studies, I have argued, is that the balance of N-terms and S-terms within it is different from, say, physics. S-terms and S-loops, present in all sciences, play a particularly constitutive role in finance theory. In a culture saturated with the prejudice that S-terms are epistemologically inferior to N-terms, that sounds like a criticism, but it is not. Physics too has its world-making and not merely world-describing aspects, as Hacking (1983) and Galison (1997) have shown us, but this is even more the case for finance theory. That finance theory makes a world rather than just describes a world adds a wider significance to its study. It is performative (as Callon 1998 would predict) but not uniformly and straightforwardly performative. The S-loops of the financial markets are complex, and as yet incompletely understood; theory's interaction with them can have unexpected effects, just as any form of social action can have unanticipated consequences (Merton 1936). Finance theory's world making exists in tension with forces undermining and resisting that world. The consequent

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dialectic is at the core of the economic history of high modernity; that, above all, makes finance a compelling object for science studies.

Notes

1. The Pentium divide bug is, of course, also of interest from quite a different point of view: that of design faults in computer systems. It is treated from that perspective in MacKenzie (forthcoming, chapter 7). "High modernity" is Anthony Giddens's (1990) term.

2. The collection in which the latter appears (Kalthoff, Rottenburg, and Wagener 2000) contains a variety of interesting material.

3. The main empirical focus of this work is the foreign exchange spot market, which is much less mathematicized than, for example, the options market.

4. See MacKenzie 2000.

5. A martingale is a stochastic process in which the expected value of a variable, conditional upon its current value, is its current value. In a game of chance that is a martingale, the expected value of a player's net gain is thus zero, and hence, the game is "fair." Financial markets are not held to be martingales in an absolute sense but to be martingales with respect to some other processes, which may, for example, include an expected general upward drift of prices. For an accessible account of "equivalent martingale measures," see Hull (2000, 498-522).

6. This exceedingly brief survey is, of course, nothing like comprehensive: it omits, for example, the important contributions of Franco Modigliani and Merton H. Miller (see Modigliani and Miller 1958; Miller and Modigliani 1961).

7. This is a brief summary of the outcome of what was actually a complex historical development involving several converging lines of work, to which I hope to return in a future paper.

8. The origins of the Chicago Board Options Exchange are described in Falloon (1998, 207-27). Again, I hope to return to the history of the Chicago Board Options Exchange in a future paper, coauthored with Yuval Millo.

9. Steinherr (1998, chapter 2) refers to "the American model of finance"; I prefer "system" because of the historical echo of the nineteenth-century "American system of manufactures" (see Hounshell 1984).

10. Data from the Bank for International Settlements: www.bis.org.

11. Swaps, for example, are valued by the notional principal sum, although this is not in fact ever exchanged and serves only to determine the magnitude of the income streams that are exchanged.

12. To the modern game theorist, this is perhaps a suggestive formulation. Nevertheless, I do not think that Keynes, writing in 1936, had this in mind.

13. Harry Markowitz, personal communication to Peter L. Bernstein, quoted in Bernstein (1992, 60).

14. I am grateful to Professor Miller (1998) for a copy of this unpublished typescript, which continues, "The characteristic Business School approach tends to be what we would call in our jargon 'micro normative.' That is, a decision-maker, be it an individual investor or a corporate manager is seen as maximizing some objective function, be it utility, expected return or shareholder value, taking the prices of securities in the market as given. In a Business School, after all, that's what you're supposed to be doing: teaching your charges how to make better decisions. To someone trained in the classical traditions of economics, however, the famous dictum of the great Alfred Marshall stands out: 'it is not the business of the economist to tell the brewer how to make beer.' The characteristic Economics Department approach thus is not micro but macro

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normative. Their models assume a world of micro optimizers and deduce from that how the market prices, which the micro optimizers take as given, actually evolve" (pp. 1-2).

15. A "future" is an exchange-traded contract for the purchase and sale of an asset at a given price on a given future date.

16. I owe this reference to Yuval Millo.

17. General Accounting Office (2000, 2).

18. I know of no academic studies of the effectiveness of momentum trading in current markets, but in early 2000, market participants told me that funds following momentum strategies had recently been achieving significant excess returns.

19. For example, empirical studies of the efficient market hypothesis found what were claimed to be excess returns to small stocks, an effect that was concentrated in the month of January. Since 1985, however, "both the small firm effect and the January effect seem to have disappeared" (Shleifer 2000, 19). That might quite conceivably be because of efforts to exploit them.

20. Bernstein (1992, 134-35) believes they would.

21. There is an accessible account of this in Wilmott (1998), from which the exposition and notation used here are largely borrowed.

22. Mathew Gladstein, personal communication to author, New York, November 15, 1999.

23. Myron Scholes, personal communication to author, San Francisco, June 15, 2000.

24. Mark Rubinstein, personal communication to author, Berkeley, California, June 12, 2000. I am grateful to Professor Rubinstein for sample copies of Black's sheets and other unpublished material.

25. There is a brief discussion in Dunbar (2000, 104-5).

26. Dunbar (2000); Perold (1999, A2).

27. An earlier version of this section appeared as MacKenzie (2000). As well as drawing on written sources (notably Perold 1999 and Dunbar 2000), this section draws on a number of interviews conducted with market participants by the author between November 1999 and June 2000.

28. See, for example, the list of Long-Term Capital Management's (LTCM) major positions on August 21, 1998, given in Perold (1999, C6-7).

29. LTCM's success and its decision in September 1997 to return much of their capital and accumulated earnings to its investors meant that the majority of the latter still made a healthy profit on their investment despite the fund's 1998 near bankruptcy.

30. Short selling an asset involves borrowing it, selling it, and later repurchasing it and returning it.

31. The fax is reproduced in Perold (1999, D1-3).

32. Consider, for example, the swap spread, the difference between the fixed rate at which interest-rate swap contracts are entered into and the yield of a government bond of maturity equivalent to the duration of the swap. From the summer of 1994 to the spring of 1998, the ten-year dollar swap spread averaged around 30 basis points (0.3 percentage points) and never fell below 25 points nor rose above 40 points (Perold 1999, C13). Its sudden jump to 60 basis points in August 1998, together with similarly dramatic movements of similar spreads, was a major cause of LTCM's difficulties. The interesting point, however, is that swap spreads have not subsequently returned to mid-1990s "normality." At the time of writing (late September 2000), the ten-year dollar swap spread stands at 114 basis points. (This figure is calculated from the bid yields of U.S. Treasury bonds with an August 2010 maturity and the quoted bid rates for ten-year dollar swaps against three-month Libor, as given in the *Financial Times*, 28 September 2000, 42.)

33. By December 1999, LTCM's founder, John Meriwether, had raised the first $250 million for a new fund, JWM Partners, which will also perform convergence arbitrage ("Meriwether's Sequel Adopts Similar Style" 1999). However, the capital base of this fund is less than that of

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LTCM, and its leverage levels are also lower, so that the sums it is devoting to convergence arbitrage are much smaller. The key difference from LTCM is that the new fund does not seem to have attracted large-scale efforts to mimic its strategies. It will be interesting to discover whether this will remain the case if the new fund succeeds in making healthy profits.

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